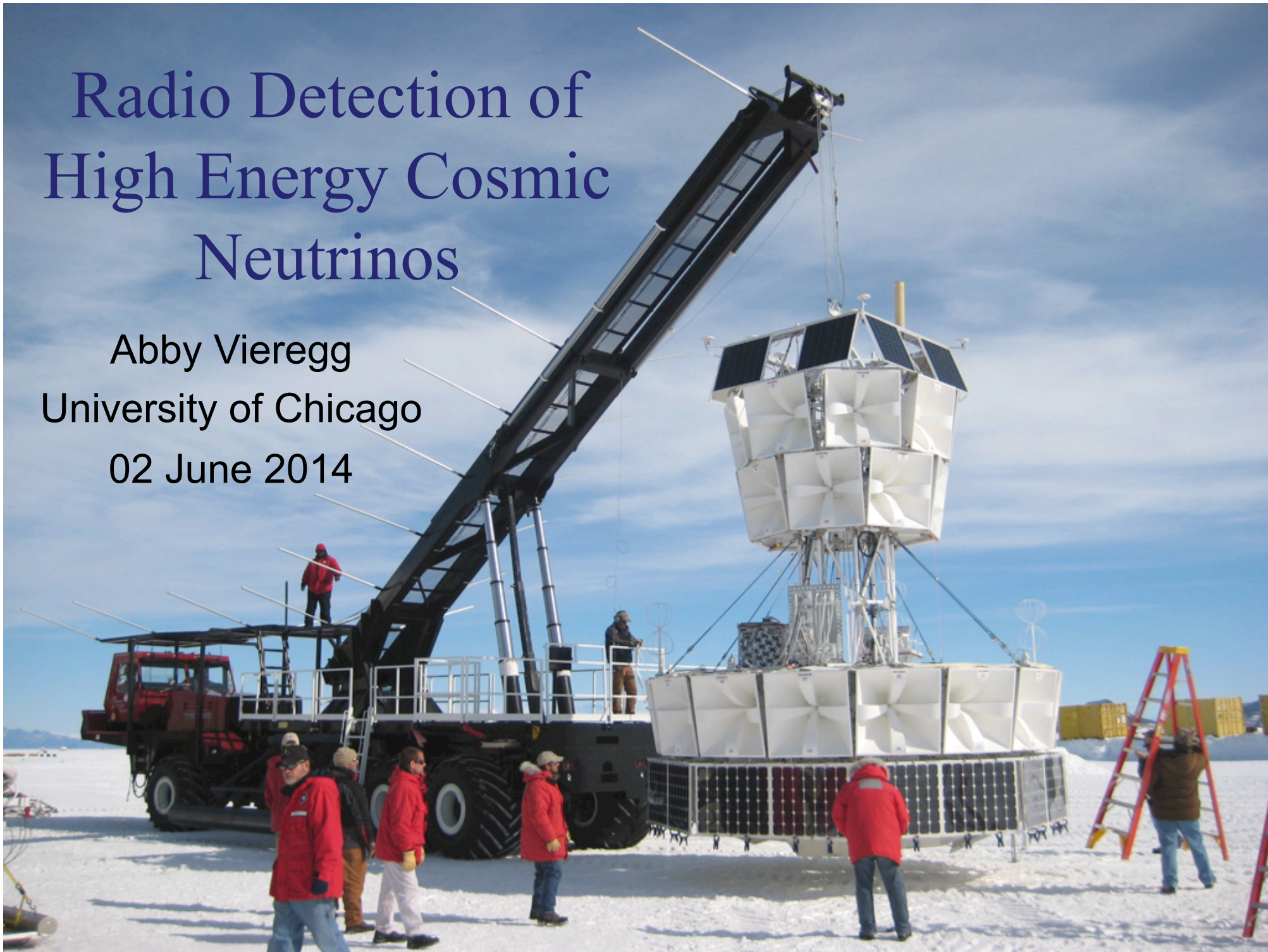


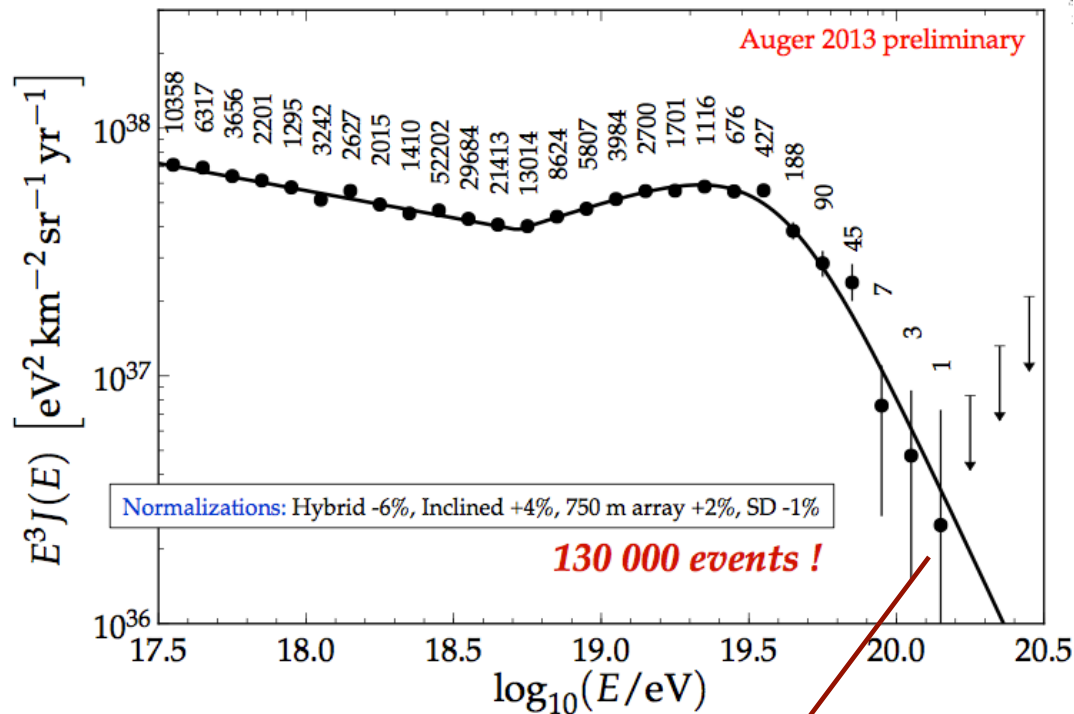
Radio Detection of High Energy Cosmic Neutrinos

Abby Vieregg
University of Chicago
02 June 2014



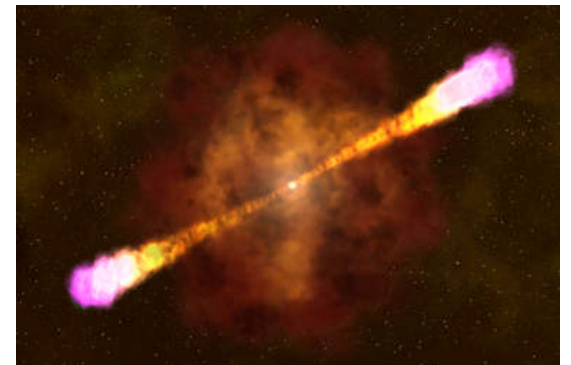
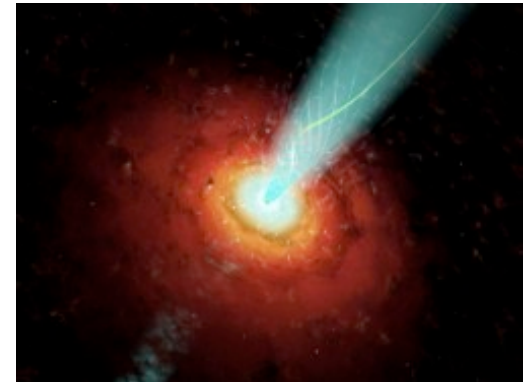
The Ultra-High Energy Universe

UHE Cosmic Ray Flux



- We know there are sources up to 10^{20} eV (1 Joule)!!
- How are these particles accelerated?
 - Active Galactic Nucleii (black holes accreting mass)?
 - Blazars (Jets emitted in our direction by AGN)?
 - Gamma Ray Bursts (most luminous events in the universe)?

(Reminder: IceCube $< 10^{15}$ eV)



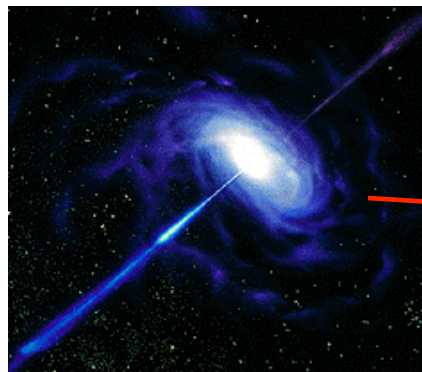
Neutrinos: The Ideal UHE Messenger

Possible Messenger Particles:

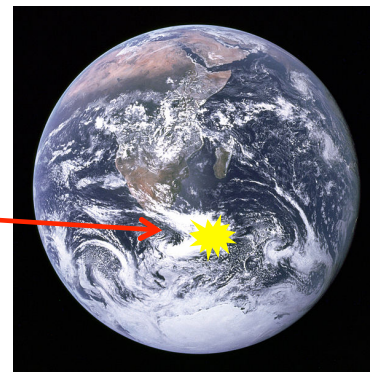
- Photons lost above 100 TeV (pair production on CMB & IR)
- Protons and Nuclei deflect in magnetic fields
- Neutrons decay
- **Neutrinos: point back to sources, travel unimpeded through universe**

UHE Neutrino Detectors:

- Open a unique window into the universe
 - Highest energy observation of extragalactic sources
 - Very distant sources
 - Deep into opaque sources
- How does the high energy universe evolve?

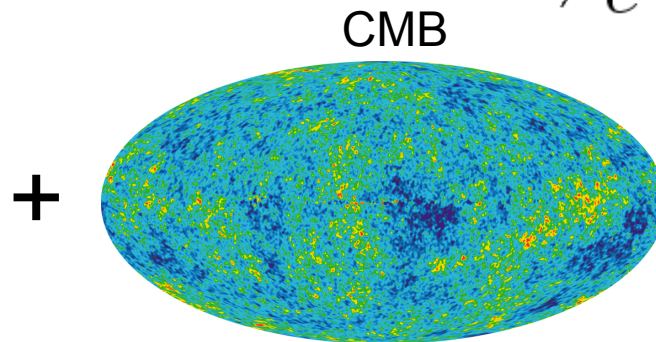
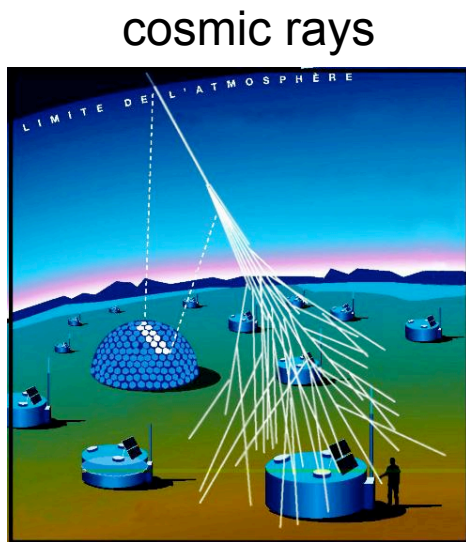
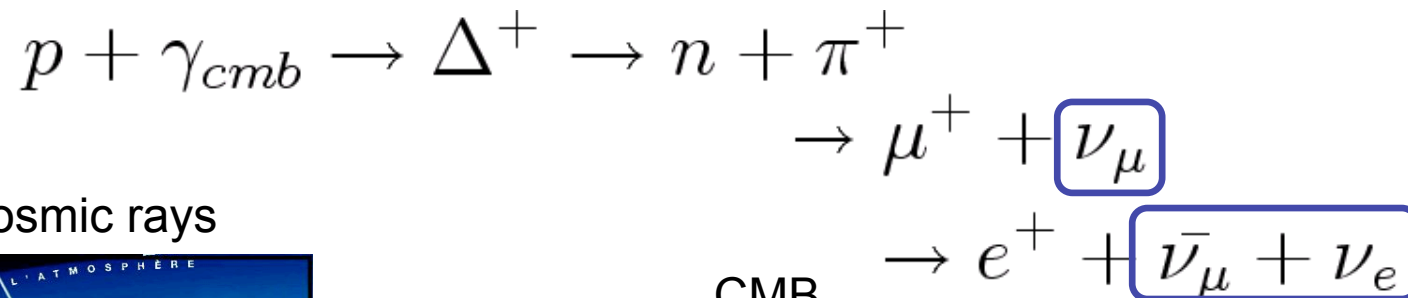


A. G. Vieregg



Neutrino Production: The GZK Process

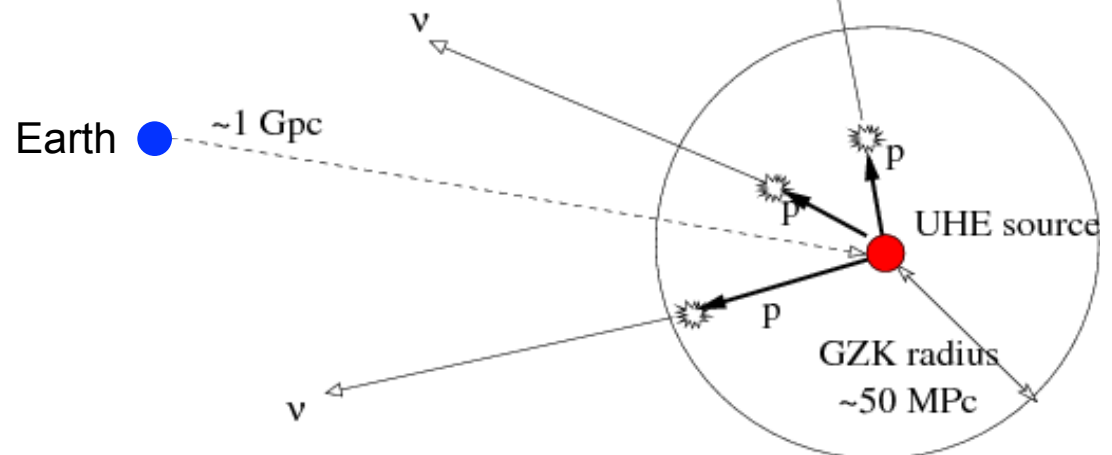
GZK process: Cosmic ray protons ($E > 10^{19.5}$ eV) interact with CMB photons



= Neutrino Beam!

Discover the origin of high energy cosmic rays through neutrinos?

What is the high energy cutoff of our universe?

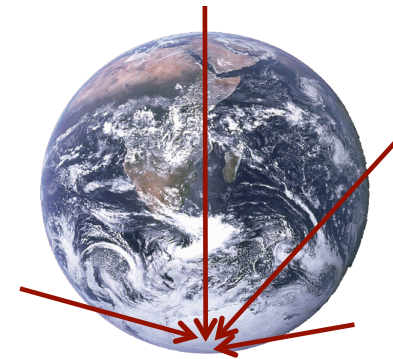
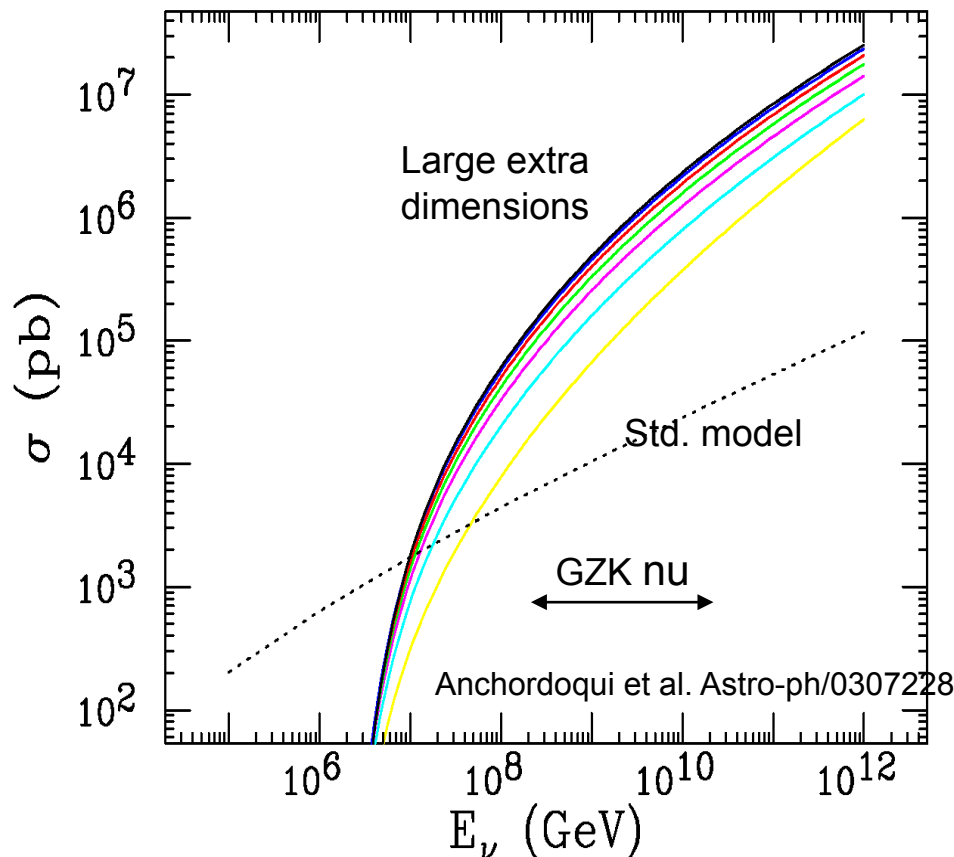


Why is UHE Neutrino Astronomy Interesting?

A Particle Physics Case

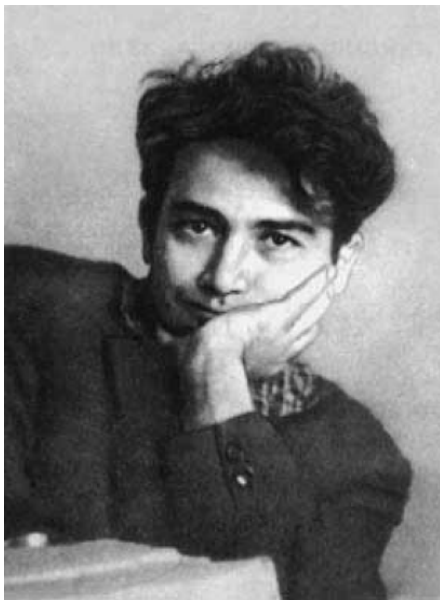
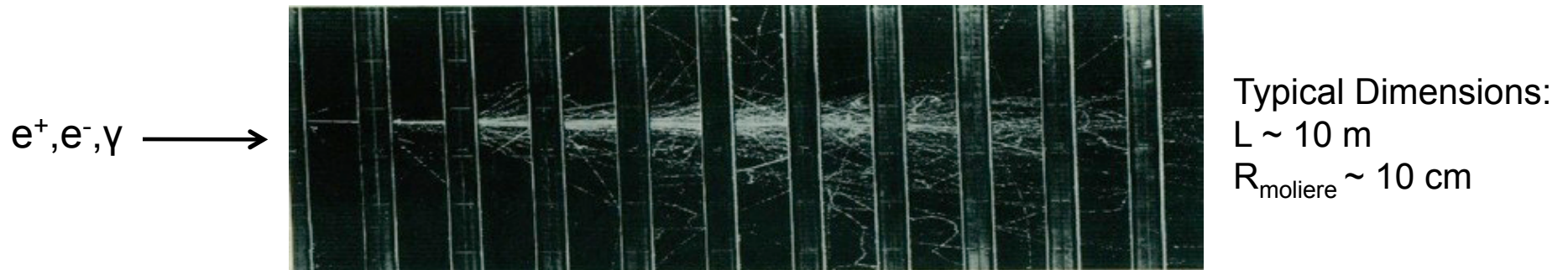
Probe particle physics interactions at energies not achievable on earth

- E_{CM} is ~ 200 TeV (LHC “only” 14 TeV)
 - Measure neutrino-nucleon cross section in a new regime
 - $L_{\text{int}} \sim 300$ km: use Earth-shielding as cross-section analyzer (count events with different path lengths through the earth)
 - Probe exotic models



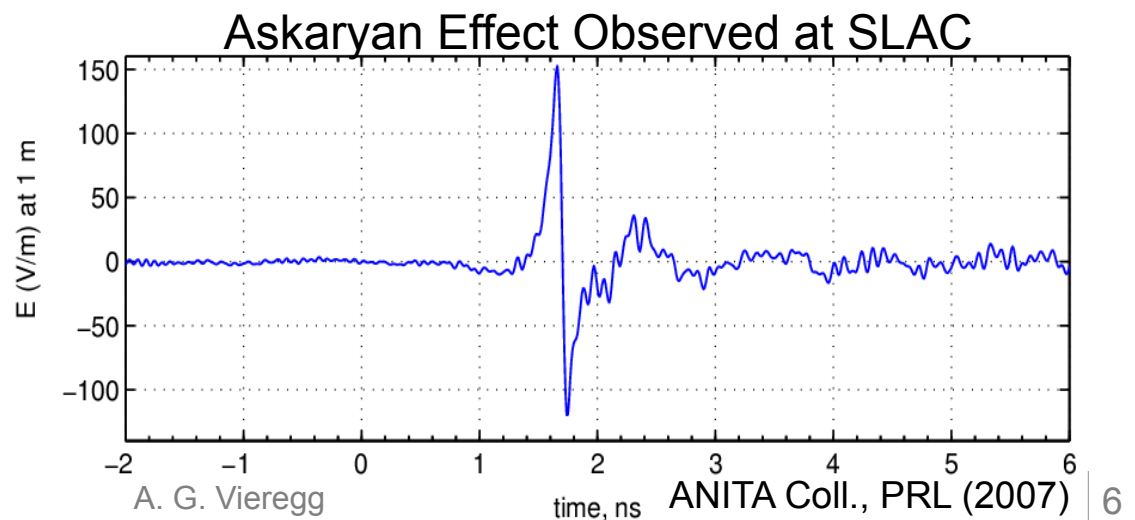
Detection Principle: The Askaryan Effect

- EM shower in dielectric (ice) \rightarrow moving negative charge excess
- Coherent radio Cherenkov radiation ($P \sim E^2$) if $\lambda >$ Moliere radius



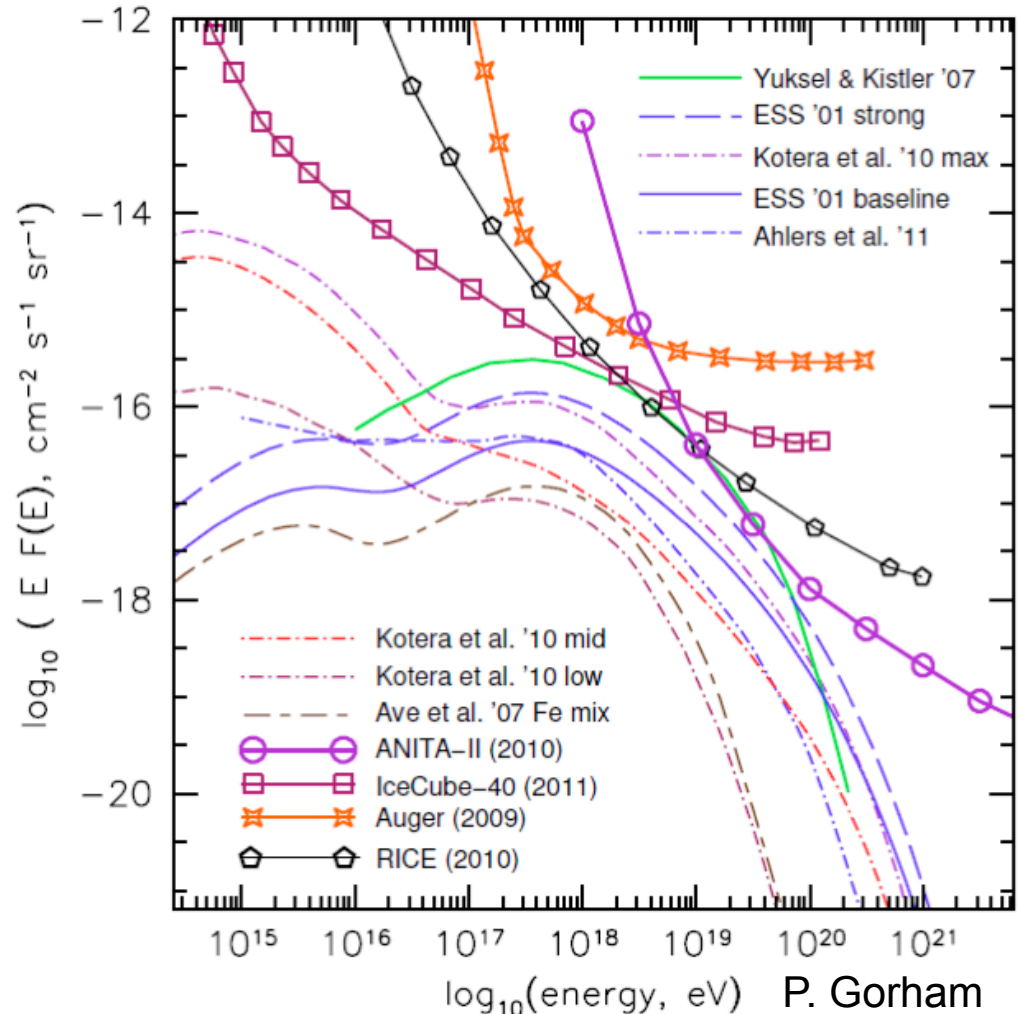
G. Askaryan

\rightarrow Radio Emission is much stronger than optical for UHE showers



Models & Current Constraints

- Best current limits:
 - $>10^{18}$ eV: Radio Detection, ANITA
 - $<10^{18}$ eV: Optical Detection, IceCube
- Starting to constrain some models (source evolution and cosmic ray composition)
- How do we get a factor of ~ 100 to dig into the interesting region and make a real UHE neutrino observatory?
- Why bother? Not a fishing expedition! There is a floor on the expectation.



ANITA-I & ANITA-II: Best Limit $> 10^{19}$ eV

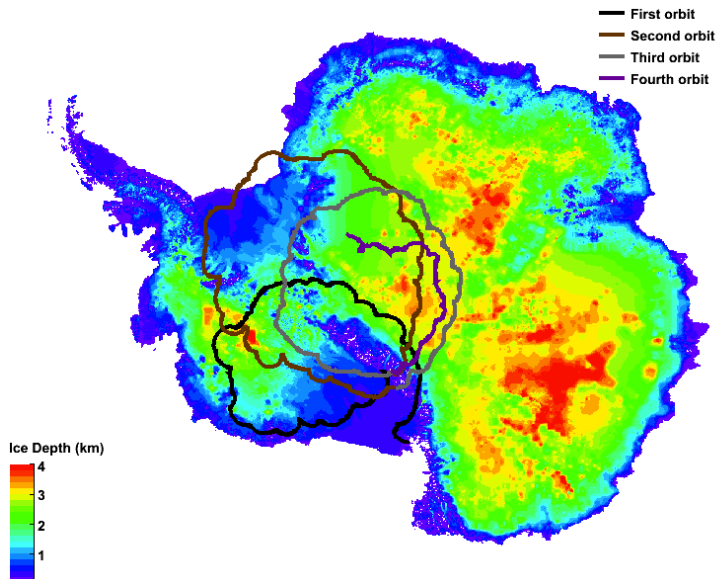
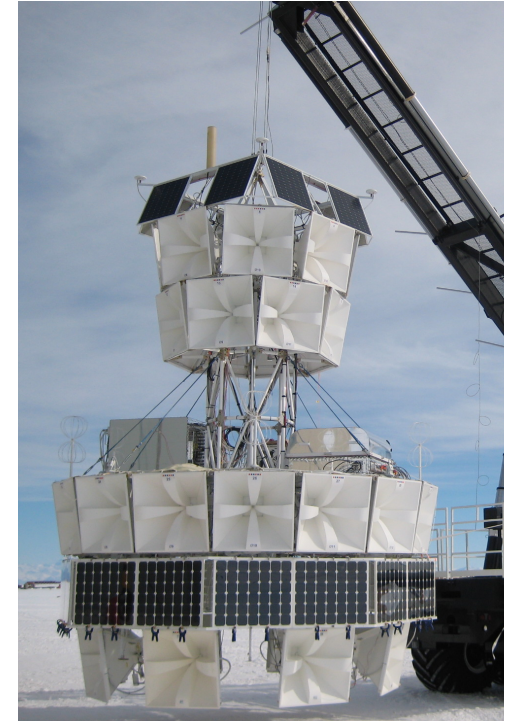
NASA Long Duration Balloon, launched from Antarctica

ANITA-I: 35 day flight 2006-07

ANITA-I: 30 day flight 2008-09

Instrument Overview:

- 40 horn antennas, 200-1200 MHz
- Direction calculated from timing delay between antennas
- In-flight calibration from ground
- Threshold limited by thermal noise

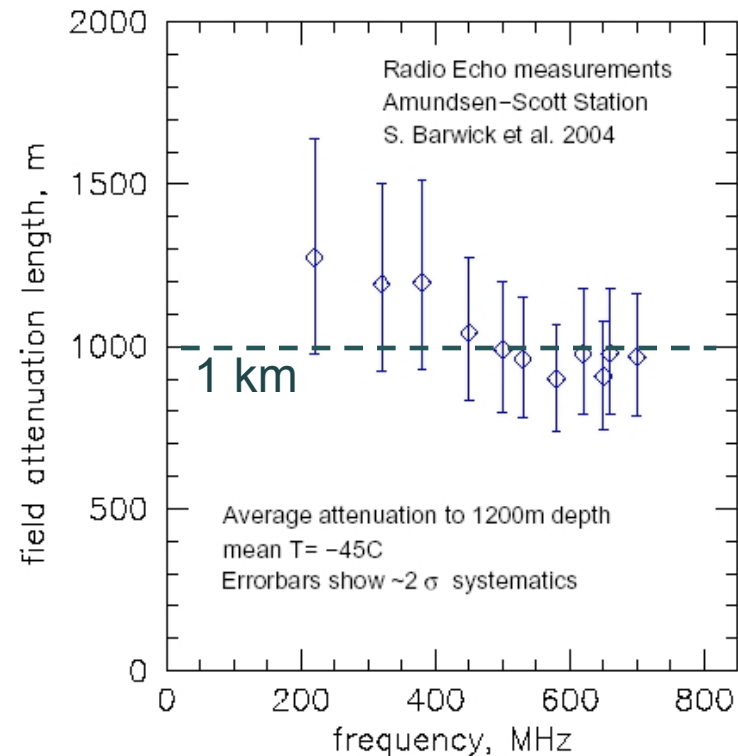


UHE Neutrino Search Results:

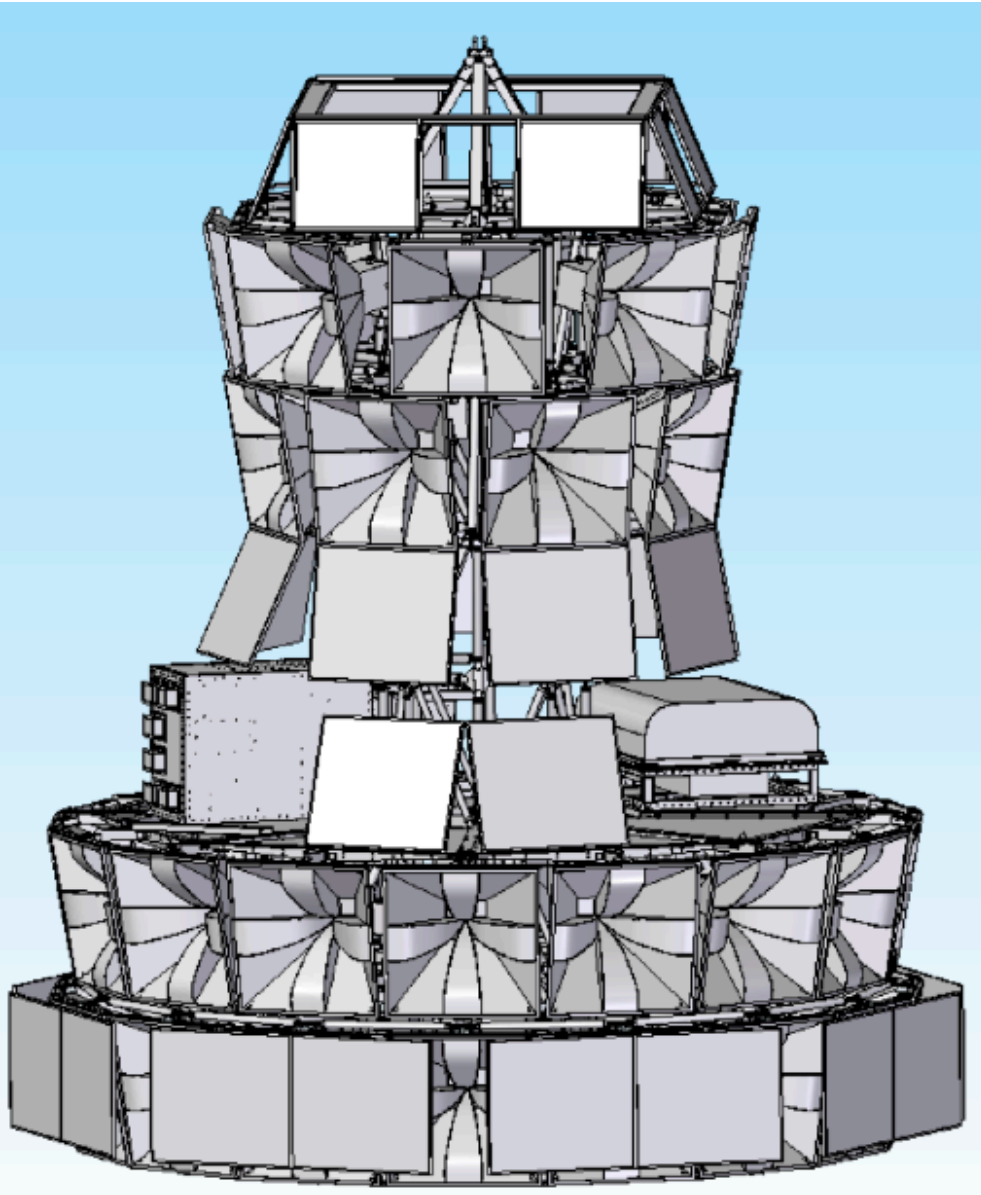
	ANITA-I	ANITA-II
Neutrino Candidate Events	1	1
Expected Background	1.1	0.97 +/- 0.42

UHE Neutrino Radio Detector Requirements

- $\sim 1\text{-}10$ GZK neutrinos/km²/year
 - $L_{\text{int}} \sim 300$ km
→ ~ 0.01 neutrinos/km³/year
 - Need a huge ($\gg 100$ km³), radio-transparent detector
 - 3 media: salt, sand, and ice
 - Long radio attenuation lengths in south pole ice
 - 1 km for RF (vs. ~ 100 m for optical signals used by IceCube)
- Ice is good for radio detection of UHE neutrinos!



ANITA-III: 2014-2015



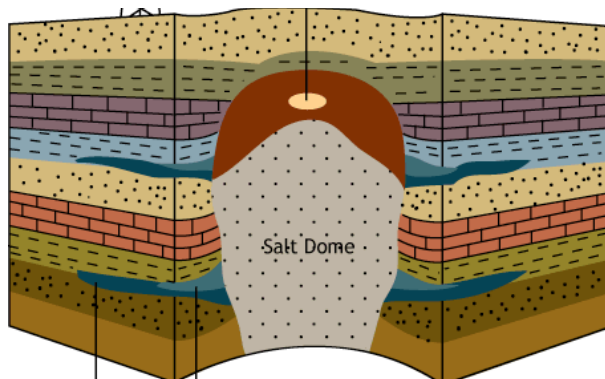
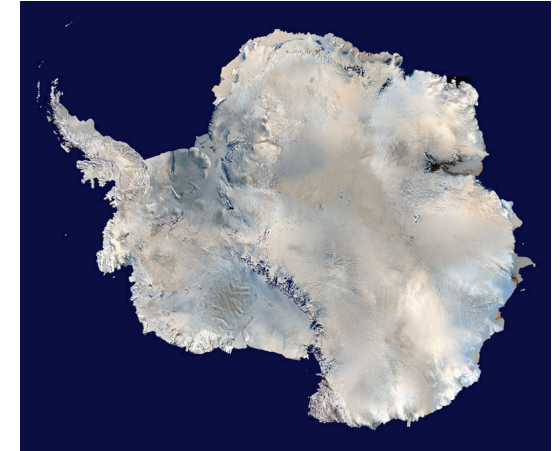
- Flight scheduled this year
- More antennas
- Digitize longer traces
- New: interferometric trigger
- Lower noise front-end RF system

→ Factor of 5 improvement in neutrino sensitivity compared to ANITA-II

Beyond ANITA: Going to the Ground

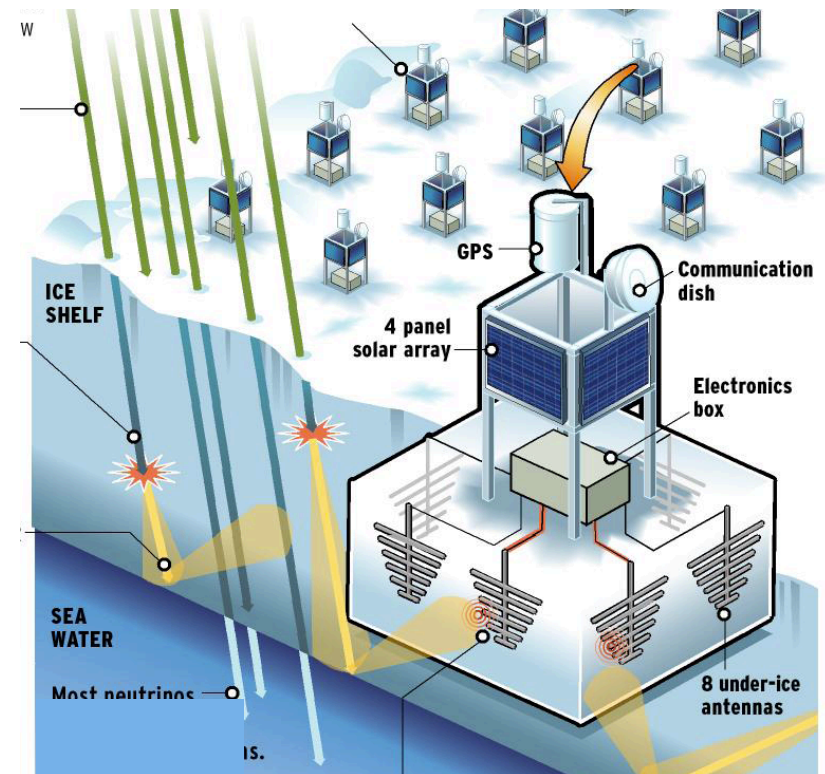
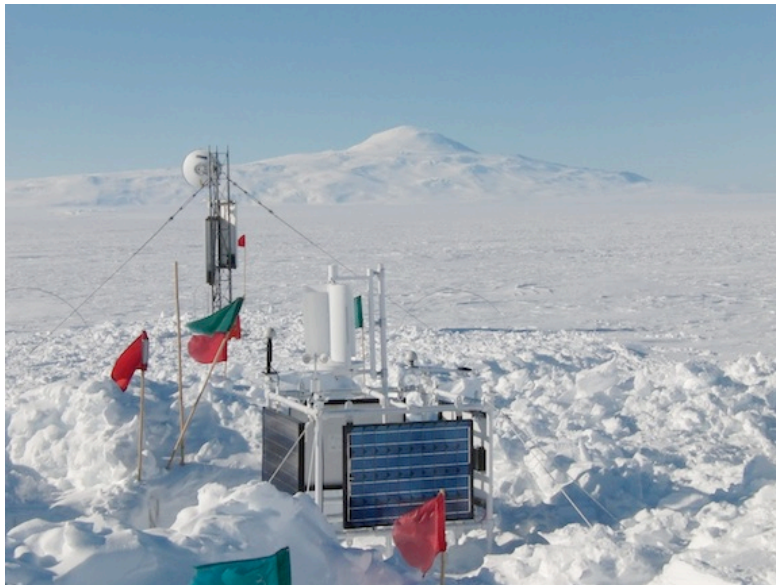
Why go to the ground?

- Much more livetime
- Understandable man-made background
- Lower energy threshold
- Use more antennas than on a balloon
- But: smaller instrumented volume



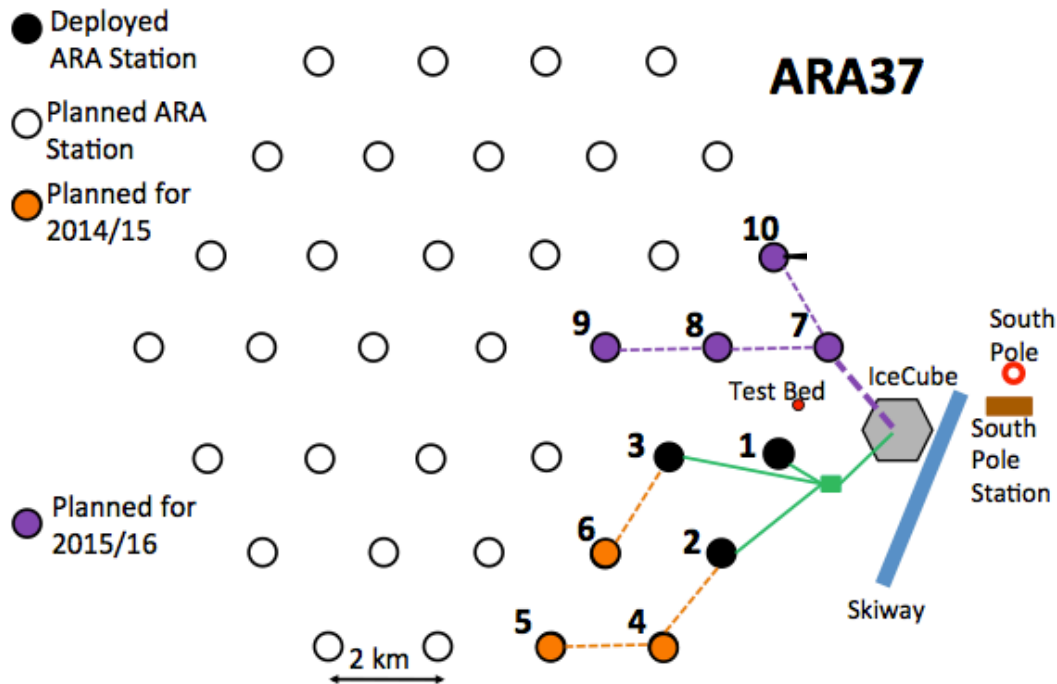
ARIANNA

- Idea: Ground-based array of antennas on the surface of the Ross Ice Shelf
- Currently: 3 stations operating well, 4 more coming in December
- Plan: proposal submitted for full array (1000 detectors)
- Solar Power: stations have operated through 58% of the year on solar power alone



ARIANNA Coll. See [arXiv:1207.3846](https://arxiv.org/abs/1207.3846)

ARA: Askaryan Radio Array



Idea: 37-station array of antennas buried 200m below the surface at the South Pole

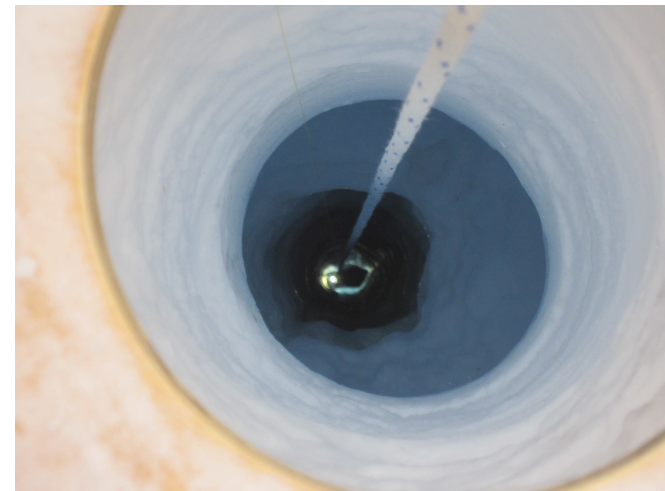
Currently: 3 stations + testbed deployed and working

Plan: Proposal pending for next stage of deployment (10 stations)

V Pol Antennas



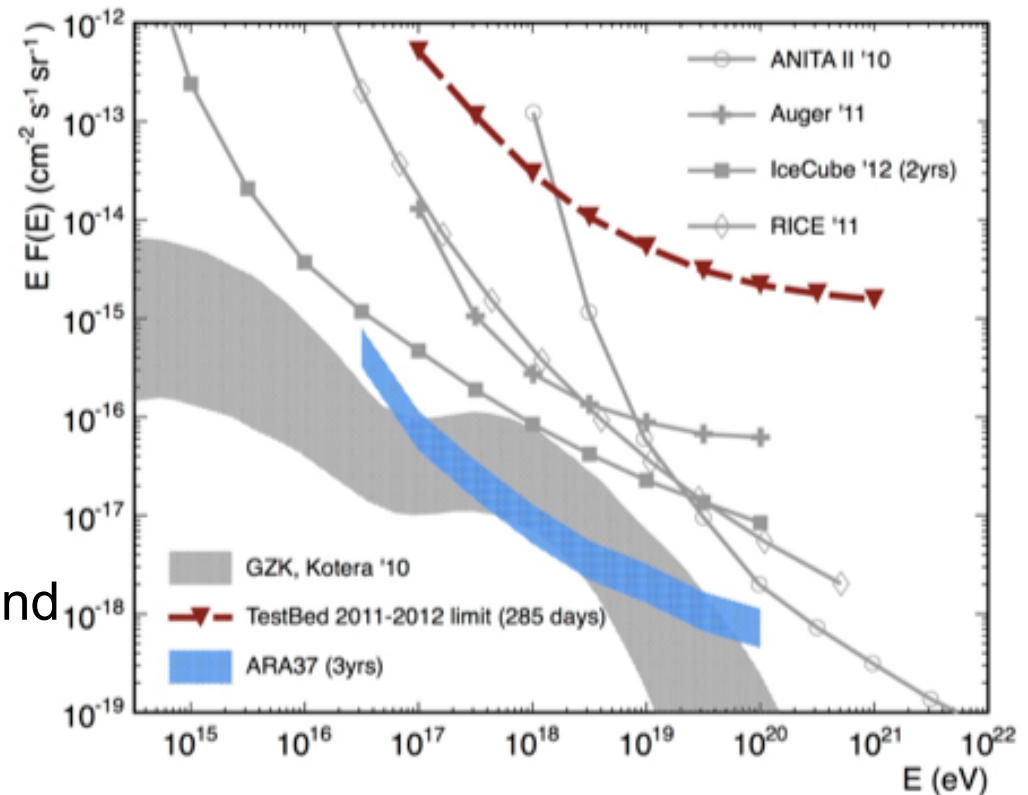
H Pol Antennas



ARA Collaboration. Astropart. Phys. (2012)

ARA Testbed Data Analysis

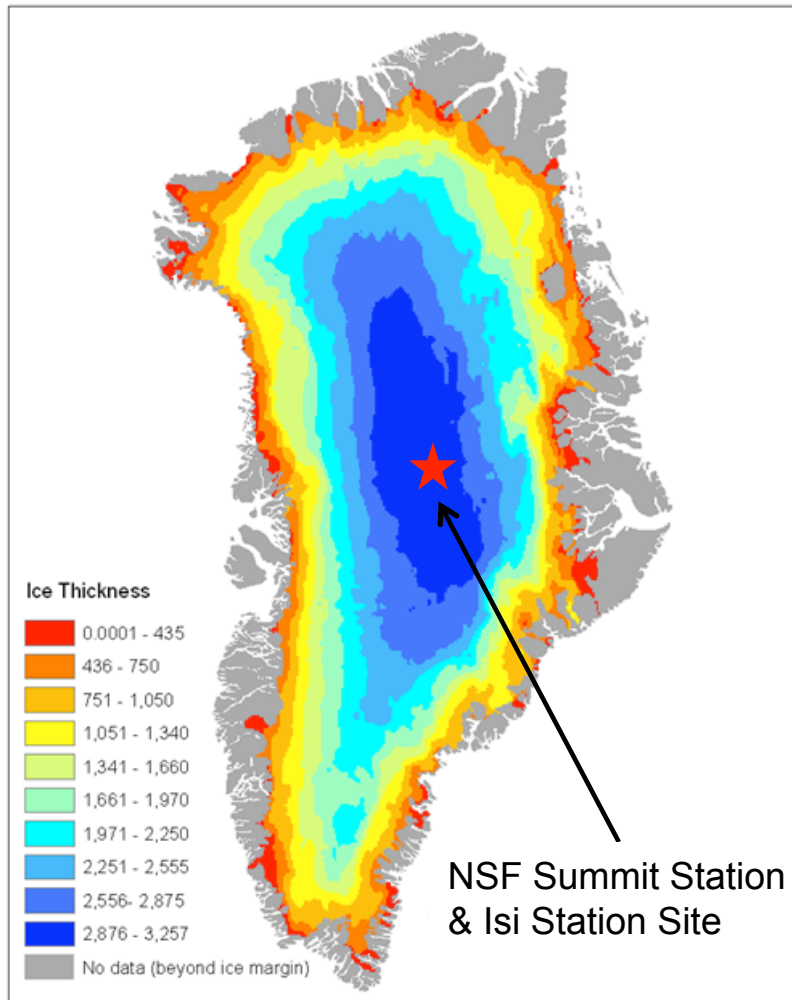
- 2011 and 2012 testbed station data
- Three independent blind analyses, look at 10% sample
- Cut-based analysis:
 - Reconstruction cuts
→ reject thermal noise background
 - Impulsiveness cuts
→ reject continuous wave background
 - Directionality cuts
→ reject man-made background
- Future: much more volume instrumented, trigger and analysis improvements for full 37-station array



ARA Collaboration: arXiv:1404.5285

Greenland Neutrino Observatory

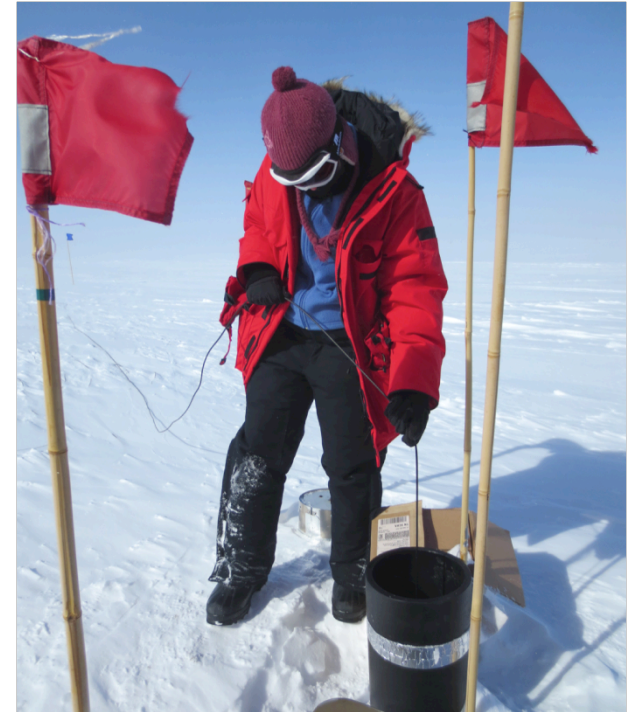
Greenland Ice Thickness



Kansas Univ. CRESIS

- Idea: array of 100 near-surface stations at Summit Station, Greenland
- 3 km thick ice
- Year-round NSF operated station with LC-130 access and annual overland traverse
- Northern Sky Coverage
- Use power from Summit Station, could use solar (10 mo/year) for large array
- Plans for a new station with expanded capacity, construction begins 2014

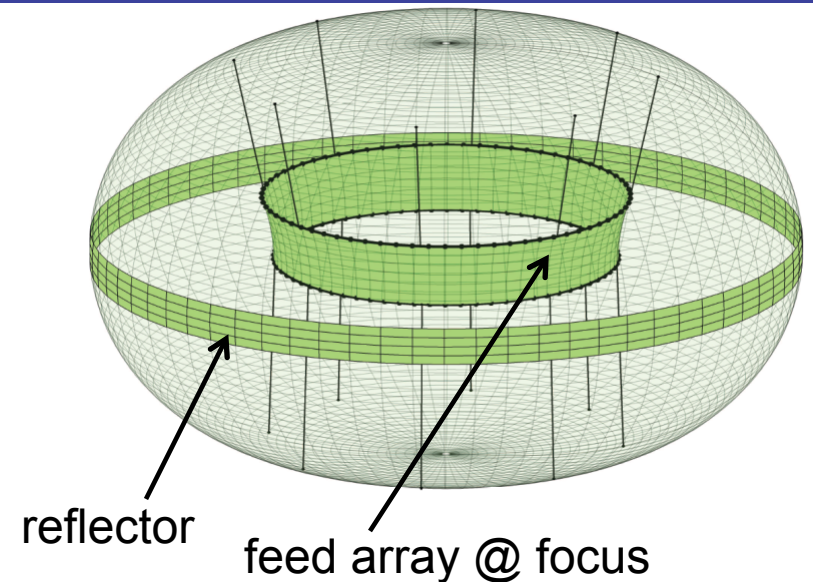
Summit Site Characterization June 2013



- Measured the attenuation length of the ice: 997 ± 150 m for top 1.5 km of ice at 300 MHz
 - Comparable to South Pole, better than other sites
- Measured firn properties: shallower surface layer than South Pole
- First-pass measurement of RF backgrounds
- Plan: deploy first neutrino-hunting station in 2015

EVA: ExaVolt Antenna

- Idea: Turn an entire NASA super pressure balloon into the antenna
- Currently: 3 year NASA grant for developing 1/5 scale engineering test, full RF + float test
- Full Balloon: similar sensitivity to full, 3-year of ground-based arrays



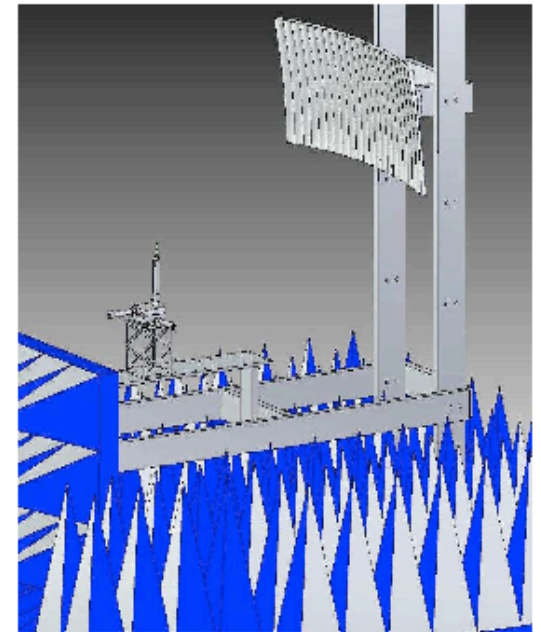
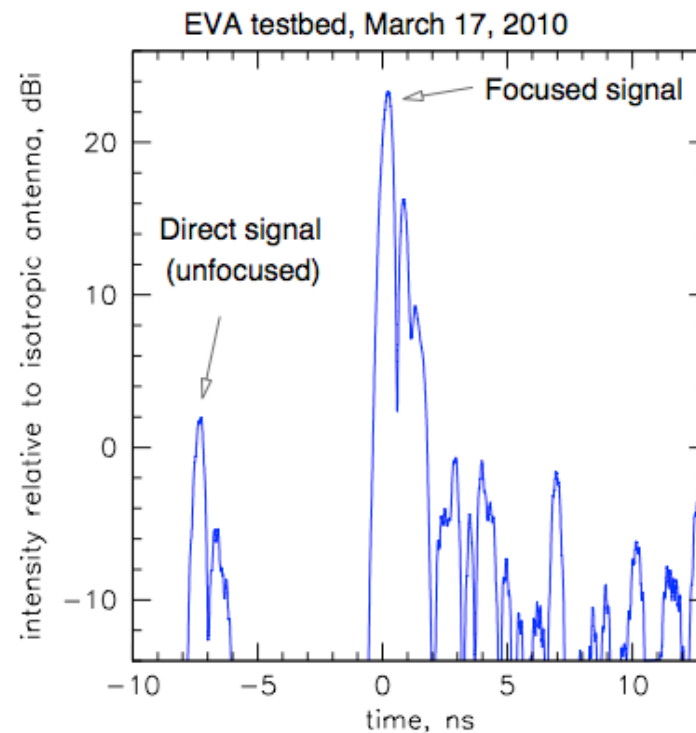
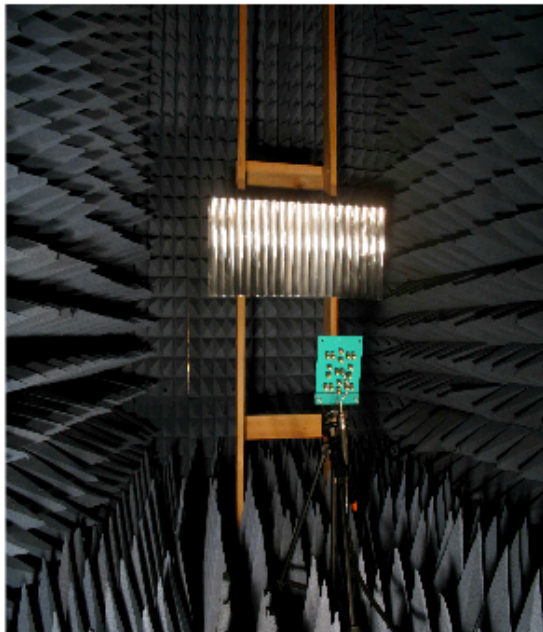
Gorham et al. (2011)



→ Feed design: dual-polarization, broadband, sinuous antennas on inner membrane

EVA Scale Model Test Results

- Microwave scale model testbed
- 1/35 and 1/26 scale models
- Measured directivity $\sim 22\text{dB}$

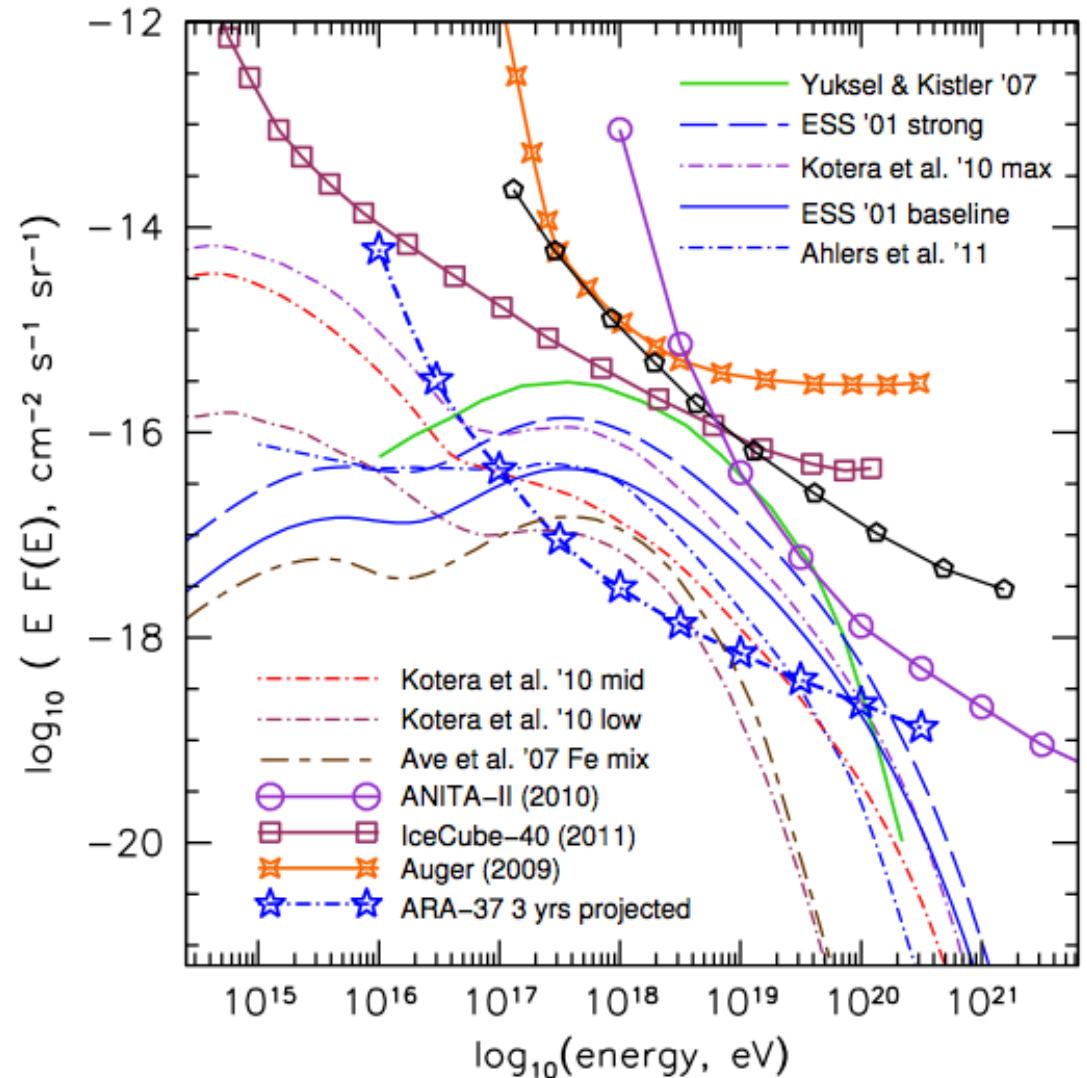


Gorham et al. (2011)

Projected UHE Neutrino Sensitivity

What the sensitivity of a next-generation UHE neutrino detector looks like:

→ With tens of events per year, we'll have a real high-energy neutrino observatory for particle physics and astrophysics



ARA Coll. arXiv:1105.2854

Summary

- It is an exciting time in the search for UHE neutrinos!
- Probing lots of fundamental particle physics and astrophysics
- Radio technique has been proven, current results constrain models
- ANITA-III 2014, IceCube ongoing
- Large forward-looking efforts in initial stages: ARIANNA, ARA, GNO, EVA
- In 5-10 years, we hope to have a real UHE neutrino observatory and to observe for many years

